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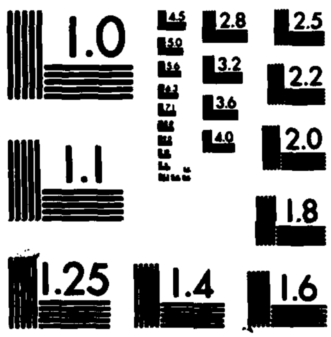

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NRL Memorandum Report 5271

UHF Propagation Measurements

F. D. QUEEN, P. A. MINTHORN, A. E. MARCH,
AND D. C. HUT

Target Characteristics Branch
Radar Division

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A system operating a 425 MHz was developed to measure propagation effects over an ocean path. The transmitter was installed on a boat and receiving antennas at heights of 6.4, 16.8, and 32 meters on a tower on Wallops Island. Data were taken during March 1983. The results are compared to theoretical curves of propagation loss generated from algorithms derived by Blake and Meeks. The experimental data falls between the two curves for 16.8 and 32 meters and follows Meeks' curve at the 6.4 meter height.

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CONTENTS

UHF PROPAGATION MEASUREMENTS

INTRODUCTION

A measurement program was carried out to verify the accuracy of propagation loss predictions at a frequency of 425 MHz. For this experiment, primary interest was in the intermediate region (near the horizon), between the interference and diffraction regions. There has been uncertainty regarding the validity of estimates of propagation loss in the intermediate region due to the necessity of interpolating between calculated values in the interference and diffraction regions. Depending on the geometry of the situation, the nearest points which could be calculated with assurance, and with ease in the interference and diffraction regions might be separated by several nautical miles, so that over a large range interval near the radar horizon, estimates were only obtained by interpolation. During the course of the investigation, the writers became aware of an algorithm described by M. L. Meeks [1], which permits accurate calculations to be made more easily at much nearer ranges in the diffraction region and even into the intermediate region. Thus, the range interval in which interpolation is required is reduced or eliminated. Experimental data are compared with calculated values obtained using the Meeks approach and using a simpler computer program developed by L. V. Blake [2].

The measurements covered a one way path over the ocean. The transmitter was installed on a 65 foot Navy patrol boat and receiving antennas were installed on a tower on Wallops Island at heights of 6.4, 16.8, and 32M (21, 55, and 105 feet). The tower was located 144M (475 feet) from the edge of the water.

The experiment was planned to cover ranges from several miles from shore to a distance where all signals were lost. Because the LORAN C equipment on the boat was inoperative, it was not possible to obtain range information far beyond the horizon. Range measurements obtained were provided by NASA using radar tracking of a C-band beacon installed on the boat.

THE MEASUREMENT SYSTEM

The system operated at 425 MHz and horizontal or vertical polarization could be used. The transmitter block diagram is shown in Figure 1a. The RF switch passed a 120 μsec sample of the CW oscillator at a 400 Hz rate. The output amplifier was capable of 300 Watts peak output, but a 2.5 dB loss in the cable to the antenna was incurred because of the below deck

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transmitter location. The antenna was a six element Yagi with a gain of 8 dB and a 60 degree beamwidth. The height of the antenna above the water was 4 meters (13 feet).

Antennas identical to the transmitting antenna were used at the receiving site. A diagram of one of the receivers is shown in Figure 1b. The leading edge of the detected pulse envelope keyed a pulse width discrimination circuit. Only pulses of duration greater than 80 μ sec could pass to the recording system.

ACQUISITION OF DATA

Data were taken on March 29, 30, and 31. Data were recorded from oscilloscope readings during the data run. During the measurement period, tides were low in the late afternoon (3:00 PM). This restricted data acquistion times because the boat had to be at the dock before low tide or wait until well after dark, which the boat crew was reluctant to do.

A total of four data runs were obtained. On the first day waves of up to nine feet were encountered and it was difficult to keep the boat oriented so that the transmit antenna was aimed toward the receiving antennas. On the second and third days the wave heights were in the three-foot range.

The maximum ranges obtained with the beacon track were 22.7 n.mi. on day one, 16 n.mi. on day two, and 18.8 n.mi. on day three.

RESULTS

The data for the outbound portion of the data run taken on the third day are shown in Figure 2 for the three antenna heights. The signal level is decreasing with R^{-4} (one way path) to a range of approximately 18.3 kM (20 kyds). The exponent increases to -4.8 at the maximum range of measurement which is about 1.8 n.mi. beyond the calculated horizon.[3]

The goal of the measurement was to compare the experimental results to those predicted. A plot of signal strength versus range (called SIGPLT) was generated using a computer program by Blake [2]. The program calculates the pattern-propagation factor F in the radar equation (modified here for the one-way path) which accounts for the fact that propagation between the two antennas may not be free-space propagation.* F is determined for each range from inputs of the antenna heights, the frequency, polarization, and wave height. The signal levels are then computed from the equation

$$S_{dB} = 20 \log (FR_0/R)$$

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*A complete discussion of this subject is contained in Ref. 4

where R_0 is the free space range. The calculation is performed to a range where the difference in path length between the direct and reflected wave is a quarter-wavelength. For the 70 cm wavelength, the range is 0.78 n.mi. To obtain signal levels between this range and a range in the diffraction region where the signal level can be calculated, an interpolation is performed.

One of the inputs to SIGPLT is the free space range. The free space range of the experimental system was determined by laboratory measurement as 230 n.mi. (Appendix A). To relate the curves of Figure 2 to Blake's curve this free space range is used. The 0-dB signal level in Figure 3 corresponds to minimum detectable signal which is the signal in free-space at the maximum range of the system. In calculating the maximum range of a system, a visibility factor (signal-to-noise ratio) is specified. If one assumes a probability of detection of 0.5 and a false alarm rate of 10^{-6} the visibility factor is 11.2 dB for a single pulse (Ref. 4 p. 2-19). Therefore, for a plot of the experimental system with a free space range of 230 n.mi., the range at which a curve of Figure 2 should cross the 0-dB level is the range at which a signal 11.2 dB above noise was received during the measurements. For the 32M (105 ft) antenna height the range for the above condition was 14.2 n.mi. Finally, to plot the curves of Figure 2, which are in relative signal strength, on the SIGPLT's of Figures 3, 4, and 5, the signal level at 14.2 n.mi. was read from Figure 2. This value of -30.4 dB then corresponds to 0 dB on SIGPLT and all relative values must be increased by 30.4 dB. The values thus obtained are plotted as circles on Figures 3, 4, and 5.

Included on the figures is a curve based on application of the algorithm by Meeks. For these curves, represented by the dashed line, the interference region was calculated as is done for SIGPLT to the point in range where the path difference between the direct and reflected waves is a quarter wavelength. The diffraction and intermediate regions are calculated using Meeks program to a range where the series does not converge. (The series involves Airy functions of complex argument). The signal level from the last range of series convergence to the range where the interference calculations was terminated is found by interpolation (Appendix B). As the calculation is performed for decreasing range, the line of sight between the target (in this case a receiving antenna) and the transmitter clears the earth's curvature. Meeks points out that the series may converge slowly or perhaps diverge when the above condition is reached.

The data for vertical polarization are shown in Figure 6. The corresponding SIGPLT for the 32M height is shown in Figure 7 with the measured data plotted as circles. The range measurement for the 12 dB S/N was slightly above 14 n.mi.

CONCLUSIONS

The results show that the experimental data for horizontal polarization tends to follow Blake's data for the 32M (105 ft) antenna height and Meeks' for the 6.4M (21 ft) height. For the 16.2M (55 ft) position the data falls between the two curves as the range increases to the range at the horizon.

These results indicate that for very low antenna and target heights the Meeks' algorithm provides slightly better agreement with measurements.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the assistance of Mr. Raymond Atkins of NASA at Wallops Island for providing support for the measurements. The assistance of the Commander and crew of the patrol boats of Special Squadron 20 of the Little Creek Amphibious Base, Norfolk is also gratefully acknowledged.

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2. L. V. Blake, "Machine Plotting of Radio/Radar Vertical-Plane Coverage Diagrams," NRL Report 7098, June 25, 1970. AD709897

3. M. I. Skolnik, Introduction to Radar Systems, page 513, McGraw-Hill Book Company, 1962.

4. M. I. Skolnik, Radar Handbook, McGraw-Hill Book Company, 1970.

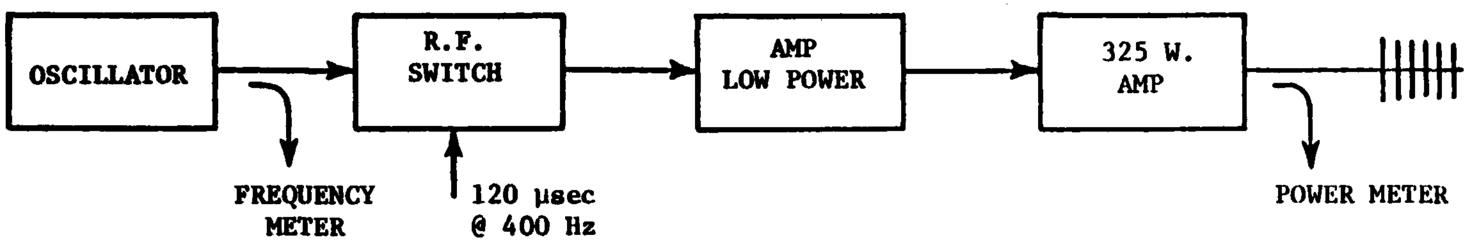

Fig. 1a. Transmitter Block Diagram.

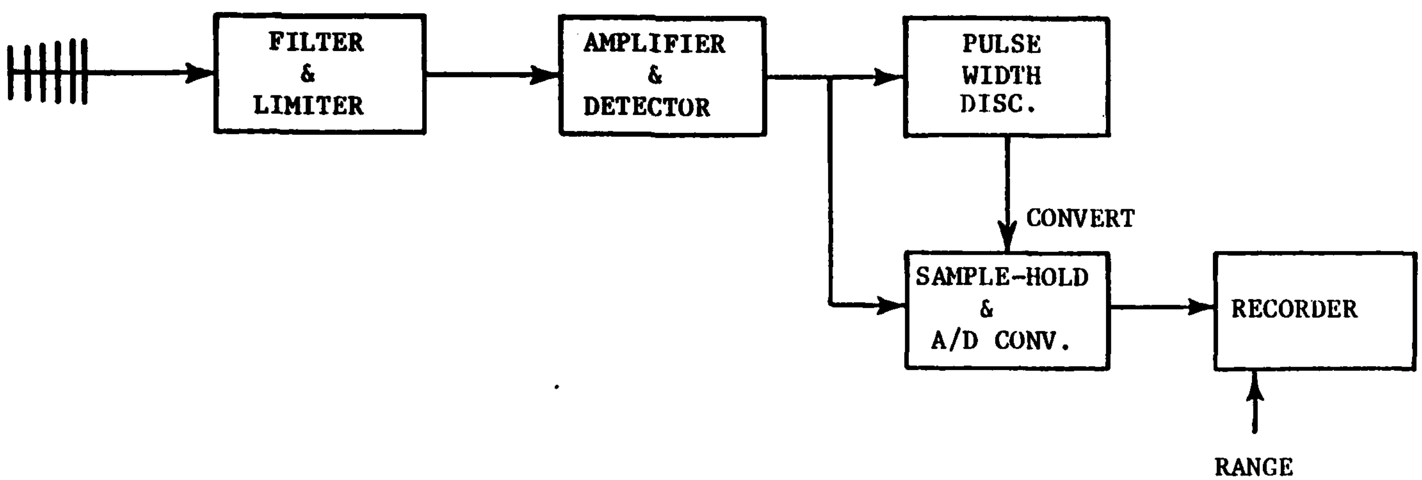

Fig. 1b. Receiver Block Diagram

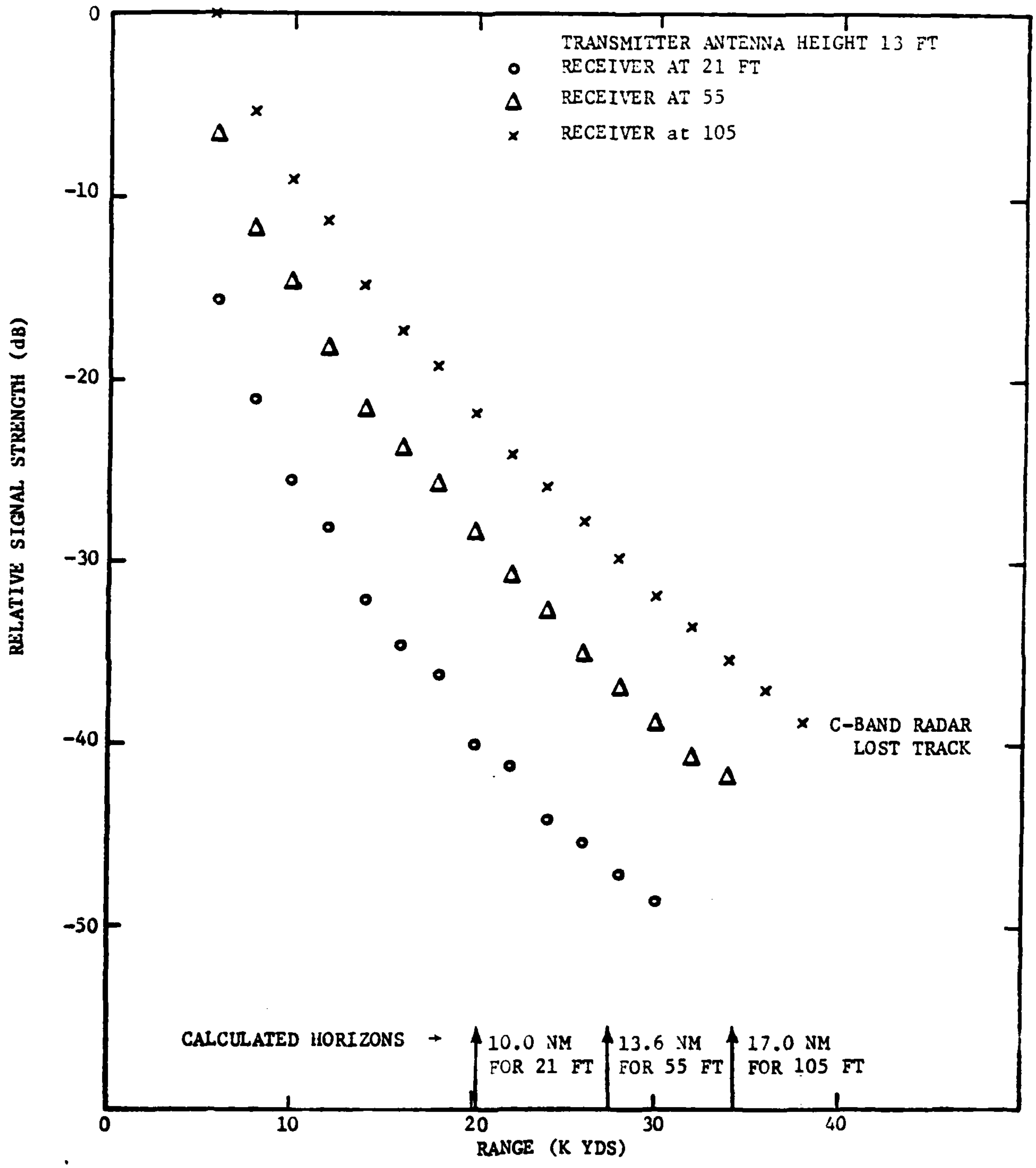

Fig. 2 Relative signal strengths at three receiving antenna heights for horizontal polarization. Ranges of calculated horizons are shown by the arrows along the range scale.

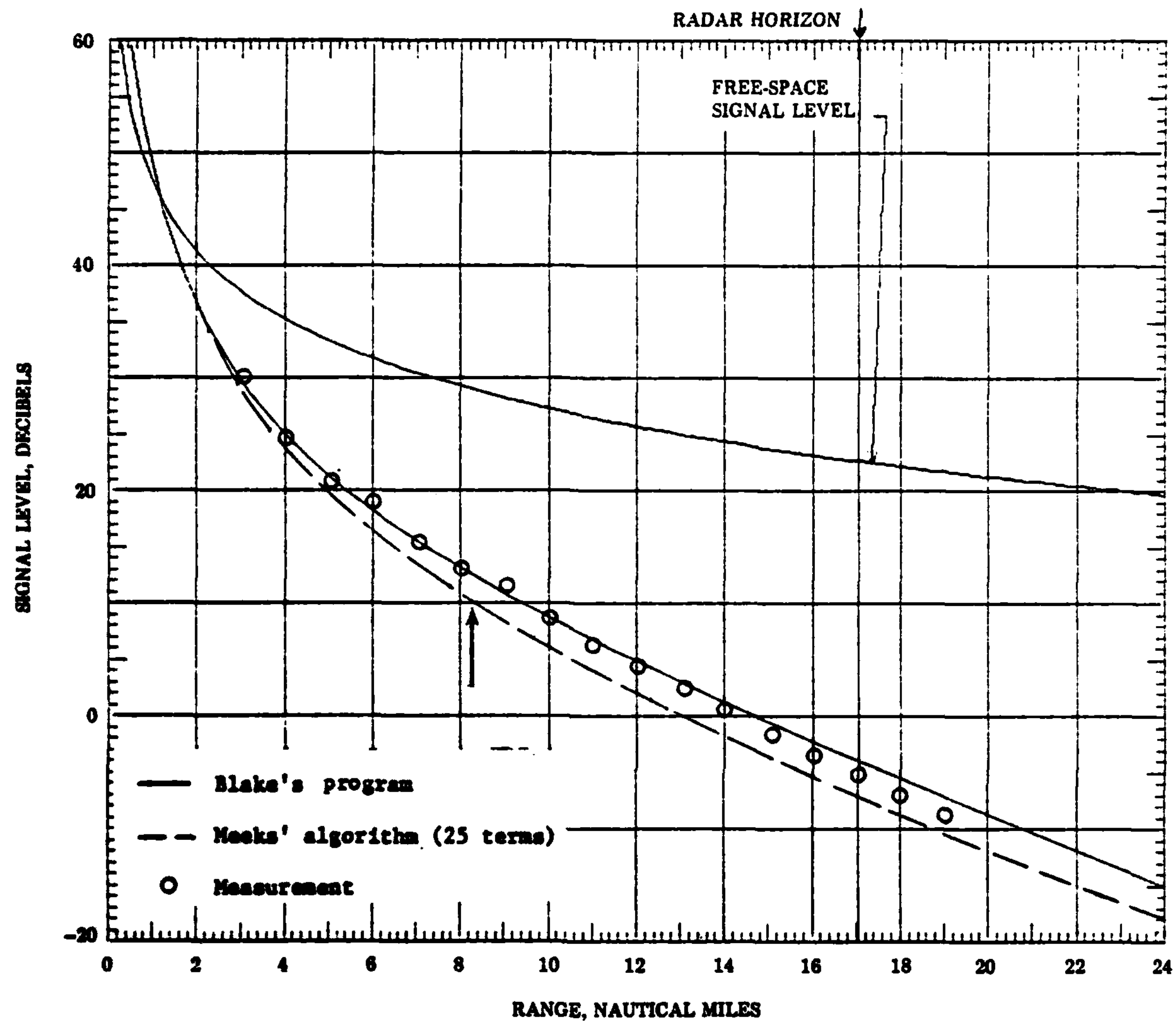

Fig. 3 Theoretical and measured data for a 13 foot transmitting antenna height and 105 foot receiving antenna height. The vertical arrow indicates the lowest range where Meeks' algorithm is used.

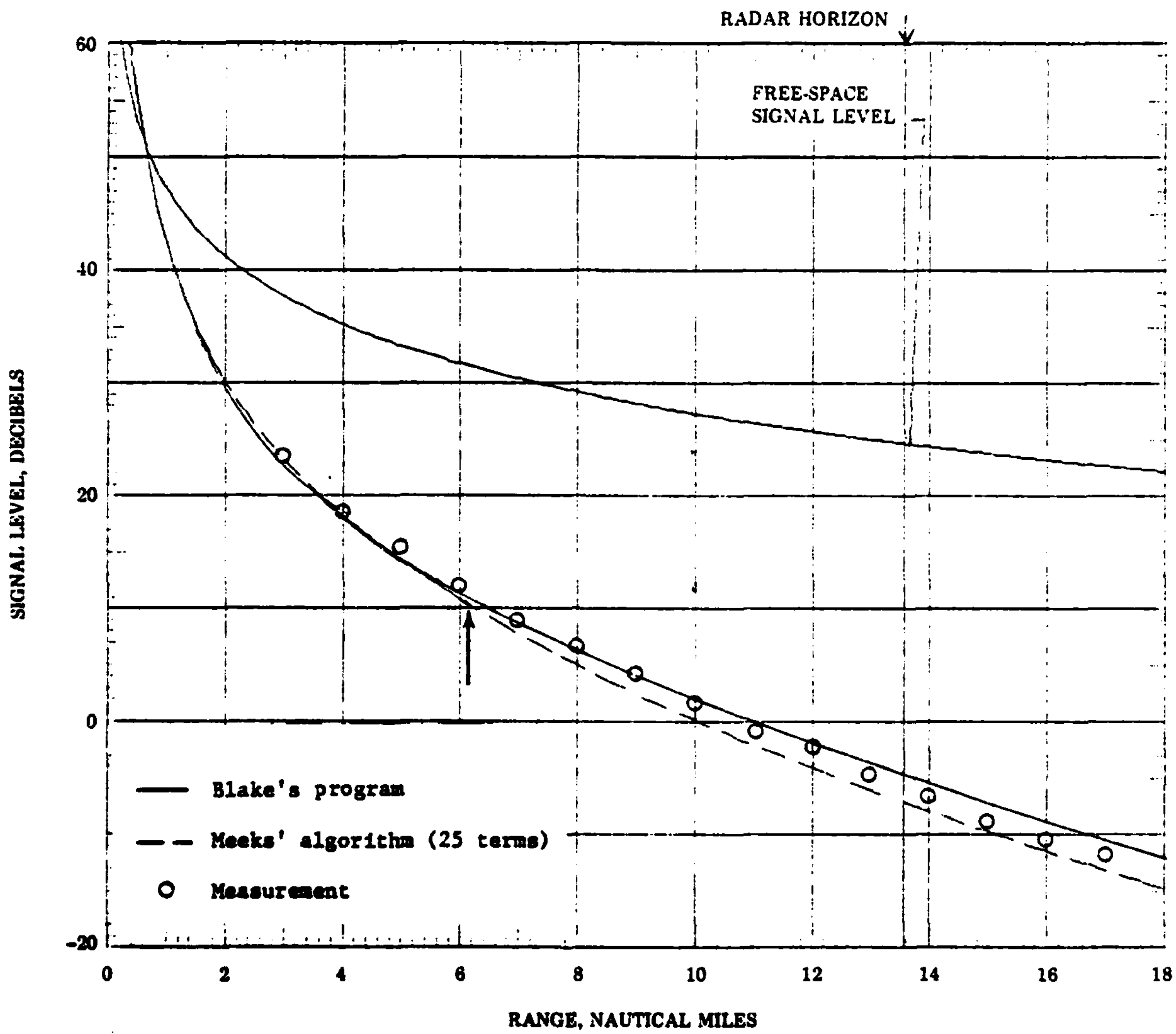

Fig. 4 Theoretical and measured data for a 13 foot transmitting antenna height and 55 foot receiving antenna height. The vertical arrow indicates the lowest range where Meeks' algorithm is used.

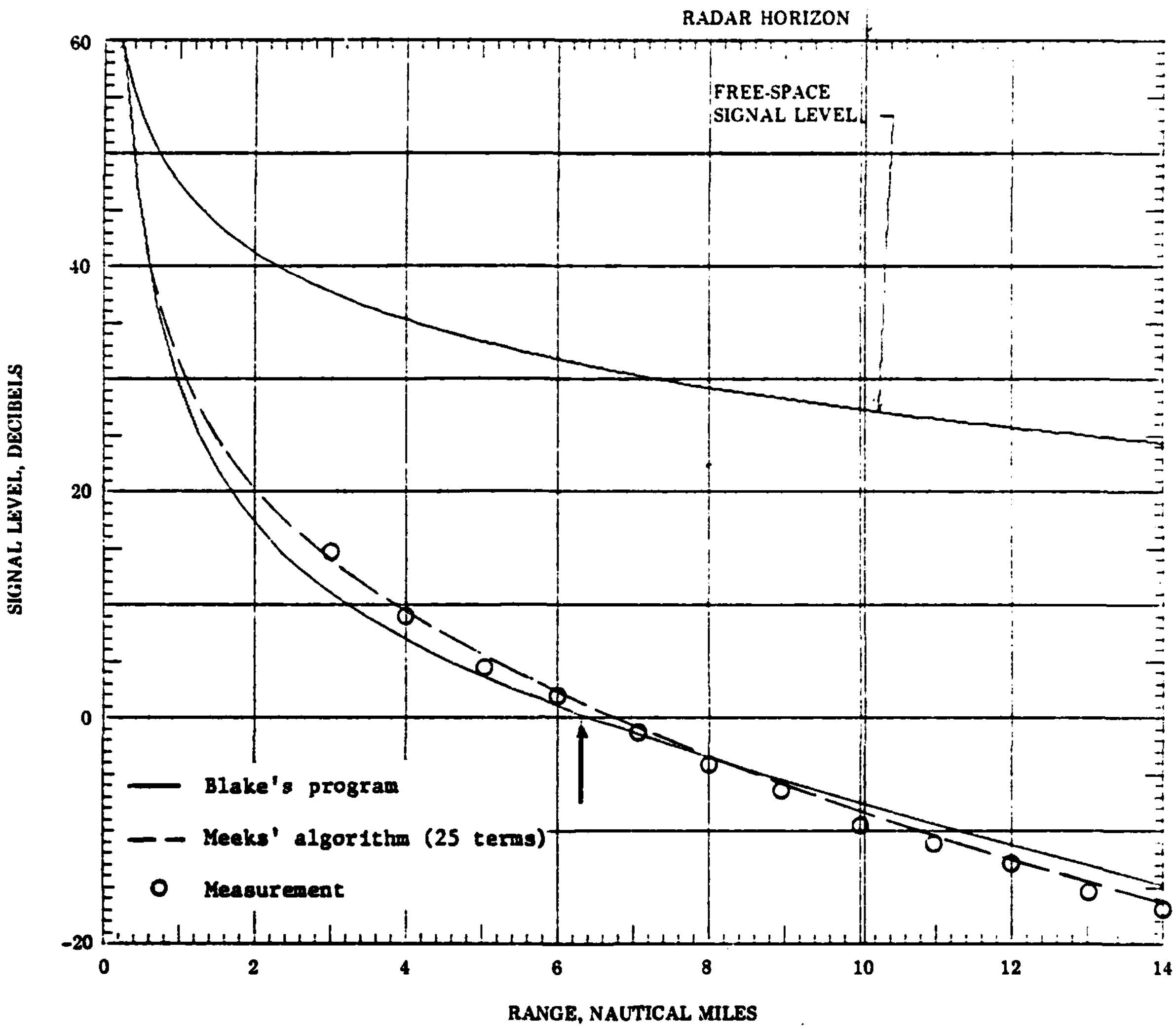

Fig. 5 Theoretical and measured data for a 13 foot transmitting antenna height and 21 foot receiving antenna height. The vertical arrow indicates the lowest range where Meeks' algorithm is used.

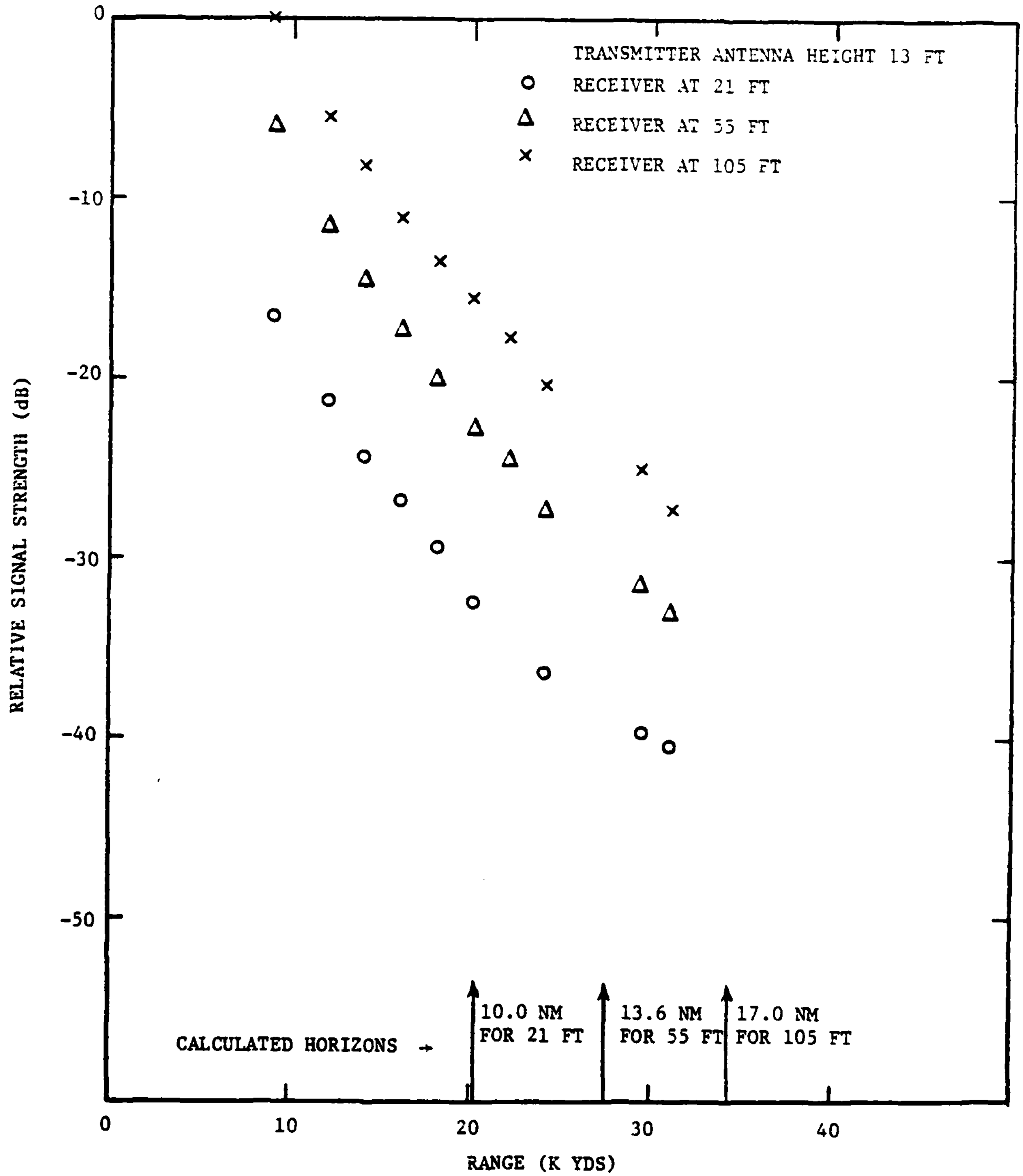

Fig. 6 Relative signal strengths at three receiving antenna heights for vertical polarization. Ranges of calculated horizons are shown by the arrows along the range scale.

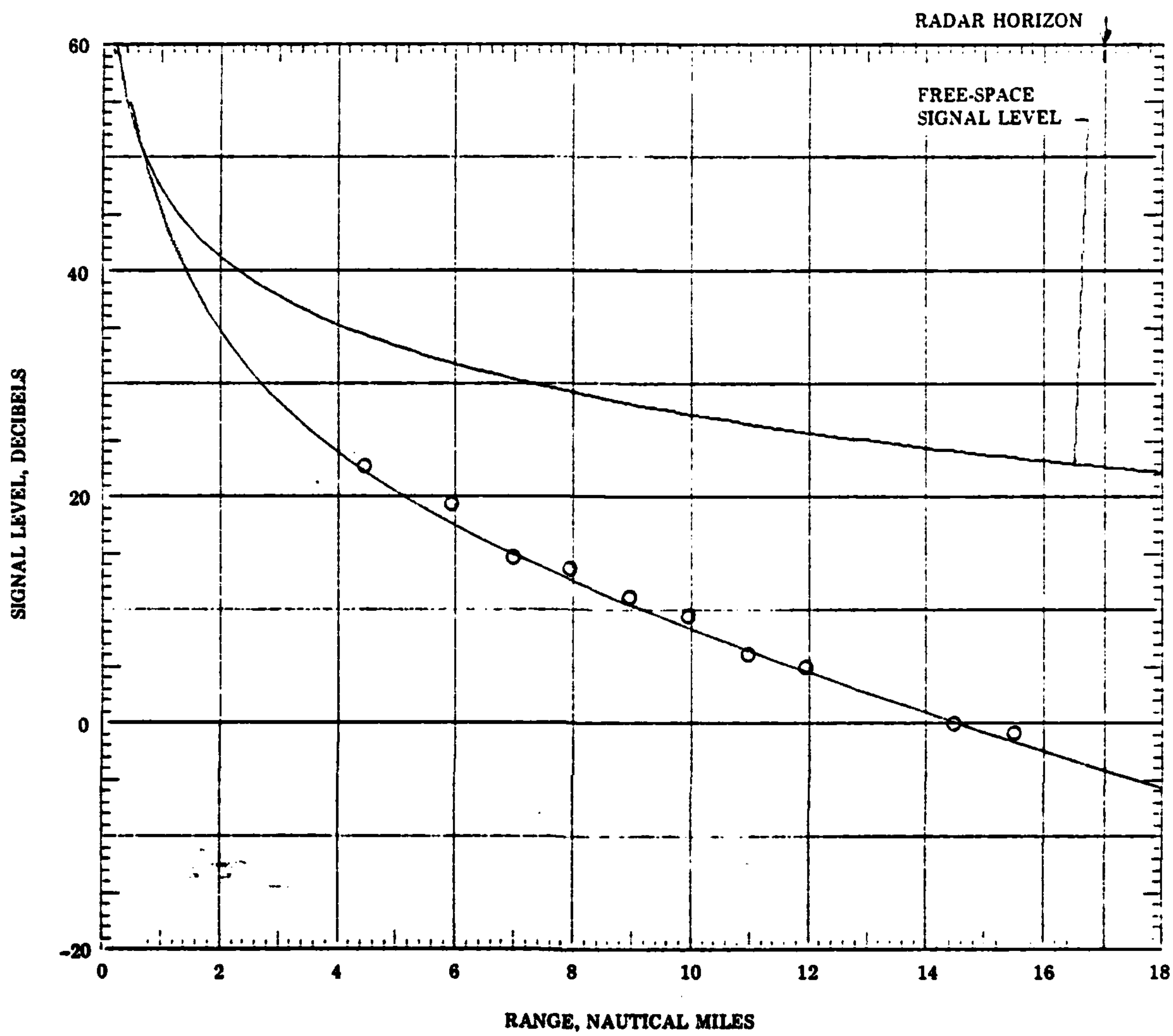

Fig. 7 Comparison of the calculated and measured signal levels for a transmitter antenna height of 13 feet and a receiving antenna height of 105 feet for a vertical polarization.

Appendix A

DETERMINATION OF THE FREE SPACE RANGE OF THE MEASUREMENT SYSTEM

For calibration purposes, the system which had been used at Wallops Island was set up between buildings at NRL. To prevent R.F. leakage from a padded high power transmitter from coupling to the receiver, a calibrated signal generator was used in place of the 300 watt transmitter. The transmitted power was 65.8 dB below the actual measurement system. The response of the receiver over a 10.4M (34 ft) measurement path was 26.5 dB above the point on the receiver transfer characteristic 12 dB above noise. Thus, the free space range would be 92.3 dB above the 10.4M (34 ft) measurement interval. This corresponds to a range of 230 n.mi.

For the above measurement to be accurate the separation of the antennas must satisfy the far field criterion, $2D^2/\lambda$, where D is the longest antenna dimension and λ is the wavelength. The effective area of the antenna is

$$A_e = G\lambda^2/4\pi$$

If this area is assumed to be circular, the diameter of the circle will be the dimension of interest. The area is

$$A_e = \pi r^2 = G\lambda^2/4\pi \quad \text{and solving for } r$$

gives

$$r = \sqrt{G\lambda^2/4\pi^2} = \lambda\sqrt{G}/2\pi$$

Substituting the diameter, D into $2D^2/\lambda$ shows the required separation to be

$$R = 2\ \lambda^2 G/\pi^2\lambda = 2\lambda G/\pi^2 .$$

The gain of the antenna is 8 dB (6.31) and λ is 2.3 feet so that the required separation is 2.9 feet. This indicates that the far field requirements were satisfied during the system calibration.

Appendix B

DISCUSSION OF SIGPLT PROGRAM

BLAKE'S PROGRAM -

The plots referenced earlier in this report were generated by the computer program SIGPLT. SIGPLT was conceived by L. V. Blake to show the level of a signal propagating over the sea, and to compare the result with the free space signal level for the same transmit/receive antenna configuration.

Calculating the curves involves first dividing the range into three regions: the interference region, the intermediate region, and the diffraction region, and then applying the appropriate solution. In the interference region, where ray optics are valid, the solution is obtained by adding the direct and reflected rays (for the reflected wave the reflection coefficient of turbulent sea is taken into account). This region extends from the antenna to a range where the path difference between the direct and reflected rays is a quarter wavelength. In the diffraction region, diffraction of the signal around the horizon is the dominant effect. The solution in this region is found from solving Maxwell's equations with a smooth, spherical earth as boundary conditions. The intermediate region is that which lies between the other two, the boundaries of which are not clearly defined. Since in this region the diffraction solution is difficult to solve analytically, and geometric optics does not apply, a method, called "Bold Interpolation" by Blake, was used. A polynomial of either second or third order is fit to four points — two at the edge of the interference region and two in the far diffraction region, where the series representation of the solution converges in a single term.

MEEKS' ALGORITHM -

A new algorithm, adapted by M. L. Meeks from theoretical work by Fock* to useful computer code, which is valid in the diffraction and intermediate regions, was added to the SIGPLT program. The solution is derived from the slowly converging series which Blake uses in his calculations in the far diffraction region. The original series of Bessel and Hankel functions is transformed into an integral representation involving the Airy functions. This solution is easier to achieve numerically.

The advantage of this method is that a large part of the plot is obtained by calculation, both in the diffraction region and in part of the intermediate region. In the unmodified SIGPLT for the 13 foot transmit antenna and the 105 foot receive antenna, the interference solution ends at 0.8 mile, with the remaining portion of the plot being derived from interpolation.

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* V. A. Fock, Electromagnetic Diffraction and Propagation Problems, Oxford: Pergrammon Press, Ltd., 1965.

The disadvantage of this method is its computation cost in certain configurations. Because the solution is in the form of a series, each term of which must be found by integrating the differential equation defining the Airy function, the computational cost can get quite large for certain configurations which require that the integration contain many more steps.

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